

## Geotechnical Investigation of Subsurface Parameters Necessary for Construction of a Flyover in Woji, Port Harcourt, Nigeria

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### ABSTRACT

Geotechnical properties of the soil have been carried out at the construction site of an overhead bridge in Port Harcourt, Rivers State, Nigeria. The project is a 230 m long overhead bridge crossing between first and second artillery in Port Harcourt, Nigeria. Two tests that were carried out on the soil are the Atterberg limit test and particle size analysis test. The results reveal that the liquid limit is 36, 8, the plastic limit is 21.1 and the plasticity index is 15.7. This implies that the Atterberg limits are slightly above the recommended standard set by the Federal Ministry for Works and Housing, however, considering the swampy wet nature of the environment within the Port Harcourt Metropolis, the results obtained still fall within a range that can be worked with few modifications. The average diameter of the particles (D value) are  $D_{10}=0.05$ ,  $D_{30}=0.17$ ,  $D_{60}=1.12$   $C_u=1.5$  and  $C_c=0.5$ . The soil sample tested shows proper gradation since the coefficient of uniformity ( $C_u$ )  $>4$ .

**Keywords:** Percentage finer, Consistency limit, Atterberg limit, Coefficient of uniformity, Coefficient of curvature.

### 1.0. Introduction

Geotechnical investigation is defined as the process of obtaining the necessary information for the physical (colour, texture, etc.) properties of the ground and also the foundation for a proposed structure and this involves a surface and subsurface exploration of the site using mechanized tools and equipment. The geotechnical investigation involves both soil mechanics and foundation engineering. Soil mechanics is a branch of geotechnical investigation that is the in-depth study of the engineering behaviour of soil when it is used as a foundation material or as a construction material (Venkatramaiah, 2006; Amosun et al., 2018), while foundation engineering is the field of study that is tasked with the design of structures which are used as a support for other structures, most especially Bridges buildings, or transportation mediums.

Consistency limits and sieve analysis have been carried out on soil samples collected at the construction site for an overhead bridge project, which is a 230 m long overhead crossing first and second artillery in Port Harcourt. The distribution and occurrence of different soils naturally vary from location to location. The types of soil depend on the mineral constituents, climatic regime, and rock type. Soils used in civil engineering structures or construction materials are found on or on the surface of the earth. Geotechnical properties of soils generally influence the stability of Civil Structures (Surendra et al., 2017).

It is also important that geotechnical investigation be carried out before any proposed structure is started because of the climatic nature of the area. Port Harcourt is located in the Niger Delta in Nigeria and this area is one of the largest wetlands in the world. The vegetation of the region is tropical rain forest and with an average rainfall of 200.45 mm yearly (Nwankwoala and Amadi, 2013), it is among the highest in the country. The effect of the climatic condition on the soil is that there is a lot of water movement and if the proper geotechnical investigation is not carried out before any proposed structural work is done, problems such as subsidence, potholes, sinking, erosion, flooding, etc. may arise in the future hence proper geotechnical investigation has to be carried out to avoid these problems. The Port Harcourt fly-over project in Rivers State, Nigeria is a set of flyovers at different locations in Rivers State. For the purpose of the study, the artillery flyover is being focused on. The artillery Port Harcourt flyover project is a 230 m long flyover which consists of 23 axes, each axis has 12 piles (fig.1) which are

cemented with pile caps and 3 columns of concrete and reinforcement supporting as pillars for the bridge itself the aim is to make the flyover strong, durable and support the load from different human and vehicular movements.



**Fig.1.** A Sectional View of an Axis Consisting of 12 piles

Some researchers stressed the need for adequate knowledge of the nature and distribution (Heterogeneity/homogeneity) of the subsurface before the construction of any engineering projects (Nnamdi et al., 2009, Ventrakamiah, 2006). According to researchers (Oghenero et al., 2014; Youdeowei and Nwankwoala, 2013; Ngah and Nwankwoala, 2013; Nwankwoala and Amadi, 2013), effective civil engineering structure design and construction prevents negative environmental impacts, structural failure, and post-construction issues. Fubara-Manuel et al., 2015; Niederleithinger et al., 2015) carried out a Geotechnical investigation for the design and construction of civil infrastructures in parts of Rivers State, they collected and tested out a total of 14 samples from 3 locations within Port Harcourt city using deep boring, percussion, and hand auger boring methods, the samples were collected using clay cutters or shield methods.

This research aims to ascertain the effect of selected geophysical parameters obtained experimentally and their effect on the construction process in general. Geotechnical investigations help to set standards on different civil parameters such as flow rate of pile concrete, the flow rate of pile cap, flow rate of column, size of stone base, size and depth of reinforcement iron, depth of pile, depth of drilling, etc.

## **2.0. Methodology**

### **2.1. Atterberg Limits**

The consistency limits also known as Atterberg limits of a soil depend on the amount and type of clay in the soil and also form the basis for the soil classification system. The consistency limits consist of three basic parameters which are:

- [1] The liquid limit
- [2] The plastic limit
- [3] The plasticity index

#### **2.1.1. Liquid Limit**

The liquid limit of a soil is defined as the lowest water content at which the soil is still in liquid form but has a small settling strength which is against flowing and which can be measured by standard procedure.

The apparatus required to measure liquid limit are a mechanical liquid limit measuring device, grooving tool (ASTM or Casagrande), porcelain container, evaporating dish, spatula, weighing balance, oven, wash bottle with distilled water, sample containers, 425 micrometer sieve.

**Procedure:** The mechanical liquid limit device is inspected to be sure it is dry, clean and in a good working condition. A sample of about 120 grams is taken from the prepared sample that passes the 425 micrometer sieve and put into the porcelain dish where a little distilled water is then added to the sample and it is now mixed to form a uniform paste with a spatula. The mixture is left to stay for 24 hours to ensure a uniform moisture distribution. A part of the paste is placed on the cap of the liquid limit device and the paste is spread round the liquid limit device with a spatula. The soil mixture is trimmed so that the highest depth of the soil is 1cm. Extra soil is transferred to the porcelain dish. The Casagrande grooving tool is used to divide the soil into two parts since the soil is clayey but if the soil is sandy, we use the ASTM type tool. The cap is lifted and dropped by rotating the handle at a rate of two revolutions per second until the two halves of the soil paste come together by flowing with the bottom of the groove. The number of blows required is taken and the reading is also recorded. It is important to ensure that the number of blows that are taken is between 15-35. From the flow sample, a sample portion is taken using a spatula into a sample dish of known weight. The moisture content of the sample is taken using standard procedures. The weight of the container,  $w_1$ , weight of the container and wet soil  $w_2$ , Weight of container and oven dry soil  $w_3$ , weight of water ( $w_2-w_1$ ), the weight of oven dry soil ( $w_3-w_1$ ) and finally the water content is measured.

The procedure is repeated for 3 more samples with a little more water added to each sample and the water content is calculated. To get the liquid limit, a graph is plotted between the number of blows taken and water content on a semi-log graph. The moisture content which is corresponding to 25 blows from the flow curve is determined as the liquid limit of the soil.

### 2.1.2. Plastic Limit

The plastic limit of a soil is defined as the moisture content when a soil just begins to crumble when rolled through a thread that is approximately 1.5 millimeters in radius.

Apparatus required: Porcelain evaporating dish, ground glass plate, metallic rod 3 mm diameter, spatula, sample container, oven, and 425 micrometer sieve.

**Procedure:** About 15 grams of soil sample passing through a 425 micron sieve is put in the porcelain dish. Distilled water is added to the soil sample and it is thoroughly mixed so that the soil mass is plastic enough to be moulded. A ball weighing about 8 grams is cut out of the prepared dish and placed on the ground glass plate. The ball placed on the ground plate is rolled so that a thread of uniform diameter is formed. The rate of rolling should be between 80 to 90 strokes per minute. The rolling continues until the thread reaches a diameter of 3 mm almost looking like the size of a metallic rod. The soil thread is now moulded back into a ball and rolled back into a thread. The process of rolling and kneading continues until the thread begins to crumble just before it attains a diameter of 3 mm, the pieces of crumbled thread are now collected in a container of known weight. The moisture content is determined using the standard procedure. The weight of container  $w_1$  is measured, weight of container and wet soil  $w_2$ , weight of oven dry soil  $w_3$ , weight of water ( $w_2-w_3$ ), weight of oven dry soil ( $w_3-w_1$ ).

This procedure is repeated 3 more times and the water content for each is gotten. The plastic limit is the average of the three moisture content.

### 2.1.3. Plasticity Index (PI)

This is the difference between the liquid limit of soil and the plastic limit of the same soil. It is given by,

$PI = LL - PL$

To classify the soil, we use the plasticity chart to determine the type of soil.

## 2.2. Sieve Analysis

Sieve analysis otherwise known as particle size analysis is the method by which we identify the number of particles of different sizes present in a soil sample. Sieve analysis is mostly done for coarse-grained soils. In this method, the soil is sieved through a set of sieves. Sieves are basically wire screens (mesh) that have square openings. The size of the opening gives the sieves their name which is called the sieve number. A sieve with a mesh opening of 4.75 mm is called a 4.75 mm sieve and similarly, a 0.6 mm sieve has a mesh size of 0.6 mm.

Sieve analysis is usually done in two ways:

[1] Wet sieve analysis

[2] Dry sieve analysis

### 2.2.1. Wet Sieve Analysis

To carry out a wet sieve analysis, we measure about 500 g of the soil sample and ensure the samples are without lumps. If there are lumps, the lumps are broken down. We measure the weight of the soil and save it as W. The soil sample is sieved through the 4.75 mm sieve. The part of the soil containing particle sizes larger than 4.75 mm remains in the mesh and this part is called the gravel fraction, the part of the soil which contains particle size that is less than 4.75 mm pass through the sieve and this portion is called a sand fraction. Hence coarse-grained soils are divided into two:

[1] Gravel fraction (fraction with grain size greater than 4.75 mm)

[2] Sand fraction. (fraction with grain size less than 4.75 mm)

After the gravel fraction and the sand fraction have been distinguished, 2 sets of sieves are set out and the dry particle size analysis begins. The sizes of sieves required for gravel fraction are sieves with mesh sizes of 80 mm, 40 mm, 10 mm, and 4.75 mm. These sieves are called set of coarse sieves. The second set of sieves used for sand fraction have mesh sizes of 2 mm, 1 mm, 0.6 mm, 0.425 mm, and 0.212 mm, these set of sieves are called set of fine sieves as it sieves finer particles of coarse soils. The sieves are arranged in decreasing order of mesh sizes i.e. the sieves with the largest mesh opening are kept at the top while those with the lowest mesh opening are kept at the bottom and the base of the sieve set is a pan that has no opening. The soil sample placed at the top is placed in the top sieve and covered with a lid. The whole arrangements are then placed on a mechanical shaker and shaken for 10 minutes. The arrangement is taken out after shaking and the amount of soil retained on each sieve and pan is weighed to an accuracy of 0.1 g. If the weight retained on each pan is W1, W2, W3, W4, W5, and W6, then we can calculate the percentage amount of soil retained on each sieve.

We also calculate the cumulative percentage retained which is the percentage retained on the sieve added to the retained weight of all the sieves above it. The cumulative percentage of soil is the weight of all the soil that could not pass through a particular sieve. We also calculate the percentage finer in which a graph called particle size distribution curve is plotted. Percentage finer is the amount of soil that passes through a particular sieve.

### 2.2.2. Dry Sieve Analysis

To carry out the dry sieve analysis, we calculate the percentage finer in which a graph called particle size distribution curve is plotted.

Percentage finer = 100% of weight – cumulative percentage retained.

This whole procedure is the dry sieve analysis. If the sample in the 0.75 mm sieve which is the final sieve before the pan is between 5-10%, then we carry out a wet sieve analysis. Wet sieve analysis aims to eliminate particles that are smaller than 0.75 mm. The sample in the 0.75 mm sieve is washed to remove finer particles/sand particles and the remaining sample in the mesh is dried in an oven for 24 hours after drying, dry sieve analysis is carried out in a known manner.

### 3.0. Results and Discussions

#### 3.1. Atterberg Limits

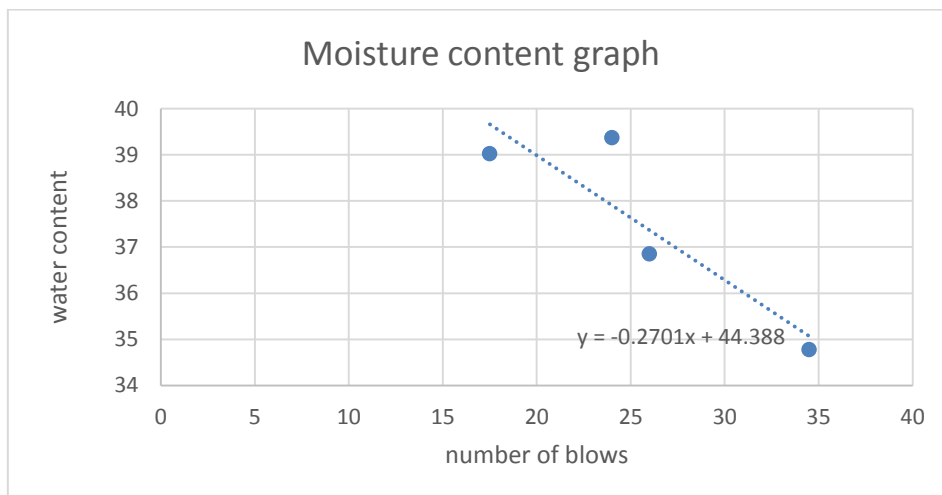
The Atterberg limits consist of the determination of:

- [1] Liquid limit
- [2] Plastic limit
- [3] Plasticity index

In the course of this work, the Atterberg limit was taken from 5 samples gotten from different locations of the site for the proposed construction. Table 1 further illustrates the procedure for getting the Atterberg limit.

**Table 1.** Determination of Atterberg limits of Soil Samples

Container number	A <sub>1</sub>	A <sub>2</sub>	B <sub>1</sub>	B <sub>2</sub>	C <sub>1</sub>	C <sub>2</sub>	D <sub>1</sub>	D <sub>2</sub>
Number of blows	17	18	23	25	27	25	25	24
Weight of container w <sub>1</sub>	20.2	20.1	21.7	21.7	23.3	24.1	23.1	23.1
Weight of wet soil + container w <sub>2</sub>	39.3	38.7	35.3	35.4	36.3	35.4	36.2	35.2
Weight of dry soil + container w <sub>3</sub>	34.2	33.0	31.1	31.8	32.7	32.2	31.4	35.1
Weight of oven dry soil w <sub>3</sub> -w <sub>1</sub>	14.1	12.4	9.7	9.8	9.1	10.9	9.1	11.0
Weight of water w <sub>5</sub>	5.2	5.4	3.4	3.7	3.1	3.8	4.7	3.8
Moisture content (w <sub>5</sub> /w <sub>4</sub> ) *100%	37.4	38.5	35.7	37.1	40.9	35.7	33.7	35.7
<b>Average moisture content</b>	<b>39.6</b>		<b>39.4</b>		<b>36.2</b>		<b>34.7</b>	



**Fig.2.** Water Content against Number of Blows

The first thing we do before determining the Atterberg limit (liquid limit, plastic limit, and plasticity index) is to determine the water content of the soil samples. To determine the plasticity index, we plot a semilog graph of water content against the number of blows. The graph (fig.2) below shows the relationship between the water content and the number of blows.

The water content corresponding to 25 blows from the flow curve which is 36.80 is the liquid limit of the soil. Recall that to determine the Atterberg limits, we determine the liquid limit, plastic limit, and the plasticity index. So far, the liquid limit has been determined i.e. 36.80. The plastic limit is determined in Table 2.

**Table 2.** Determination of Plastic Limit

Container Number	A <sub>1</sub>	A <sub>2</sub>	B <sub>1</sub>	B <sub>2</sub>	C <sub>1</sub>	C <sub>2</sub>	D <sub>1</sub>	D <sub>2</sub>
No of blows	20	23	22	24	26	23	25	30
Weight of container	26.1	21.8	22.3	20.1	21.3	19.9	23.4	21.9
Weight of wet soil + container	32.3	34.7	31.3	29.4	33.7	29.9	33.2	30.2
Weight of dry soil + container	31.2	32.5	29.8	27.9	31.2	28.5	31.2	29.5
Weight of oven dry soil	5.2	10.6	7.5	7.8	9.9	8.5	7.8	7.2
Weight of water	1.1	2.2	1.5	1.5	1.6	2.5	2.0	1.1
Moisture content	21.3	20.9	21.2	20.1	25.1	19.9	25.6	15.3
Average moisture content	21.1		20.3		22.6		20.5	
Total moisture content	21.1							

The value of the plastic limit is 21.1.

The plasticity index is the difference between the liquid limit and the plastic limit. Hence plasticity index = 15.7.

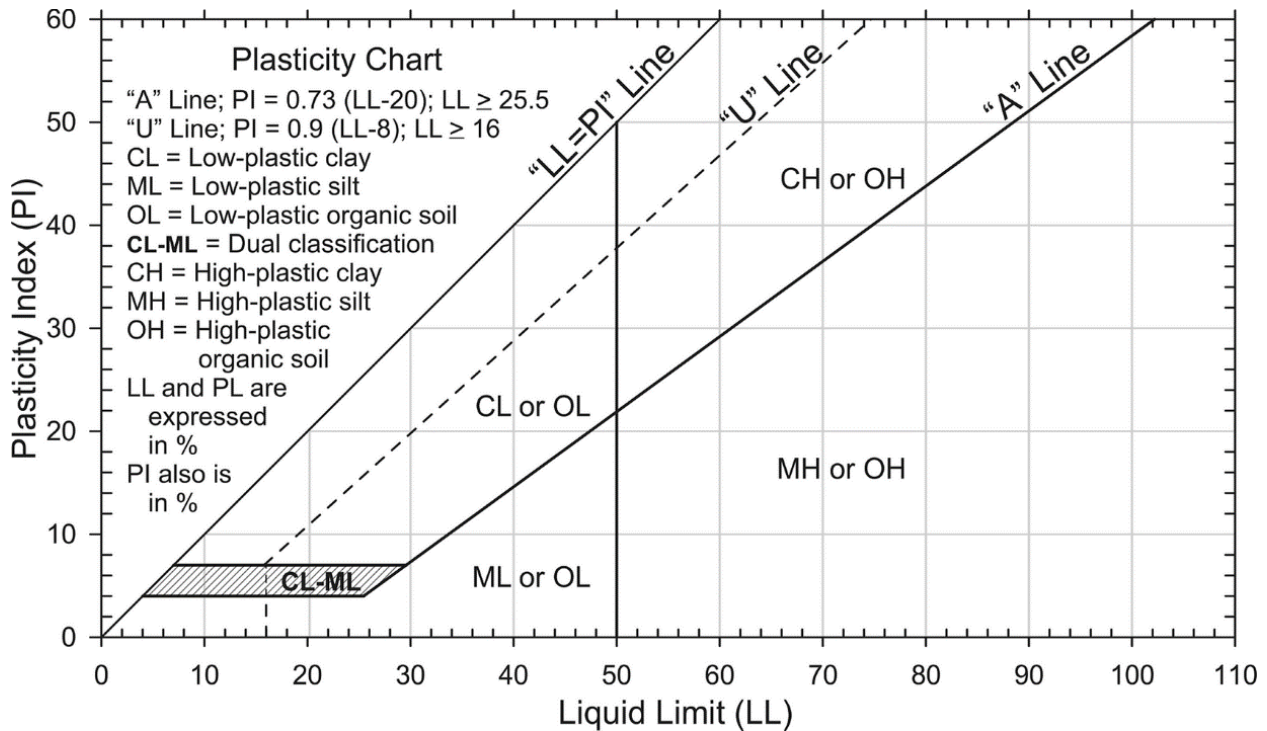
**Table 3.** Atterberg limits

Liquid limit	Plastic limit	Plasticity index
36.8	21.1	15.7

To determine the properties of the soil from the Atterberg limits according to the Unified Soil Classification System (USCS), using the plasticity chart shown in fig.3, we see that the soil present at the construction site has been classified as low plasticity clay, low plasticity organic soil and low plasticity silt indicating low compressive strength.

According to the standard that has been set by the Federal Ministry of Works and Housing for Atterberg limit testing, if we are using the American society testing methods, the liquid limit should not be more than 35% and the plasticity index should not be more than 12% which means the Plastic limit should have a value of at least 23%. For the work done so far, the liquid limit value gotten was 36%, the plastic limit was 21% and the plasticity index was 15%, these values are slightly above the standards that have been set by the Federal Ministry of Works and Housing for Atterberg limits test in Nigeria. However, a part of every construction process is cost evaluation. Hence, it is recommended that the soil be used with caution and discretion of the professional construction personnel on site and where necessary more tests and corrections are carried out on them before usage.





**Fig.3.** Plasticity Chart

### 3.2. Sieve Analysis Test

The sieve analysis test is used to determine the particle size distribution and the information gotten is used to determine compliance with design and production requirements and also for soil classification. The result of the test is the grain size distribution curve (figs.4-6). This curve is a plot of soil diameter versus the percentage of a dry sample by weight that is smaller than that diameter. Most natural soils contain a variety of particle sizes mixed. The three general classifications of soils by size are:

- [1] Fine soils
- [2] Sands
- [3] Gravels

The particle size distribution is represented on a semi-log plot. The particle size distribution is used to delineate the different soil (gravel, sand, silt, and clay) in the soil.

Some parameters that are gotten from the particle size distribution graph are:

- [1]  $D_{10}$  which is the diameter of the particles in which 10% of the soil is finer
- [2]  $D_{30}$  which is the diameter of the particles in which 30% of the soil is finer
- [3]  $D_{60}$  which is the diameter of the particles in which 60% of the soil is finer
- [4] Coefficient of uniformity and coefficient of curvature. Poorly graded soils have a coefficient of uniformity  $< 4$ . Well graded soils have coefficient of curvature between 1 and 3 with flat gradation curves.

Table 4 below shows the value of sieve analysis experimental samples carried out in the laboratory.

**Table 4.** Sieve Analysis Values

Sieve	Weight retained	% retained	% passed
<b>Sample 1</b>			
9.5	0	0	0
4.75	15.3	3.06	96.94
2.36	117.8	23.56	76.44
1.18	211.5	42.3	57.7
0.06	278.1	55.62	44.38
0.3	33.4	66.28	33.72
0.15	338.7	77.74	22.26
0.75	434.1	86.8	13.2
<b>Sample 2</b>			
9.5	0	0	100
4.75	12.1	2.42	97.58
2.36	99.7	19.94	80.06
1.18	18.3	36.6	63.4
0.06	251.2	50.24	49.76
0.3	309.9	61.98	38.02
0.15	374.5	74.9	25.1
0.75	428.1	85.62	14.38
<b>Sample 3</b>			
9.5	0	0	100
4.75	13.7	2.74	97.26
2.36	108.8	21.76	78.24
1.18	197.3	39.46	60.54
0.06	264.7	52.94	47.66
0.3	320.7	64.14	35.86
0.15	381.6	76.32	23.68
0.75	431.1	86.22	13.78

The particle size distribution helps to give a picture of the relative proportions of different grain sizes within a soil mass. Some important grain sizes such as  $D_{10}$ ,  $D_{30}$ , and  $D_{60}$  have been outlined; these grain sizes are used to determine the coefficient of uniformity and the coefficient of curvature which is further used to describe the shape of the graph.

1. A coarse grain soil is well graded if it has soil grains that represent a large range of different sizes
2. A sand is well graded if  $C_u > 6$  and  $C_c$  is between 1-3
3. Gravel is well graded if  $C_u > 4$  and  $C_c$  is between 1-3.

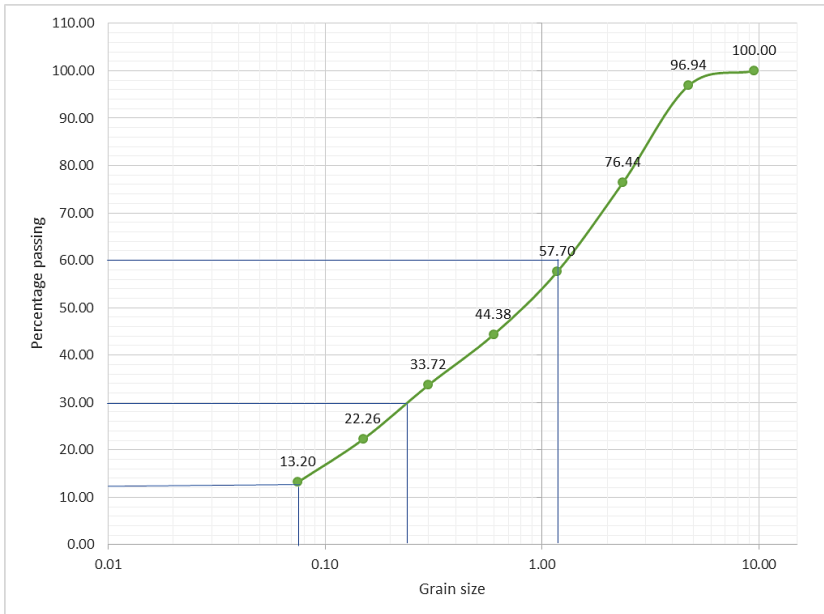
$$C_u = \frac{D_{60}}{D_{10}}$$



And

$$C_c = \frac{D_{30}^2}{D_{10} * D_{60}}$$

Where  $C_u$  is the coefficient of uniformity and  $C_c$  is the coefficient of curvature.



**Fig.4.** Sieve Analysis for Sample 1

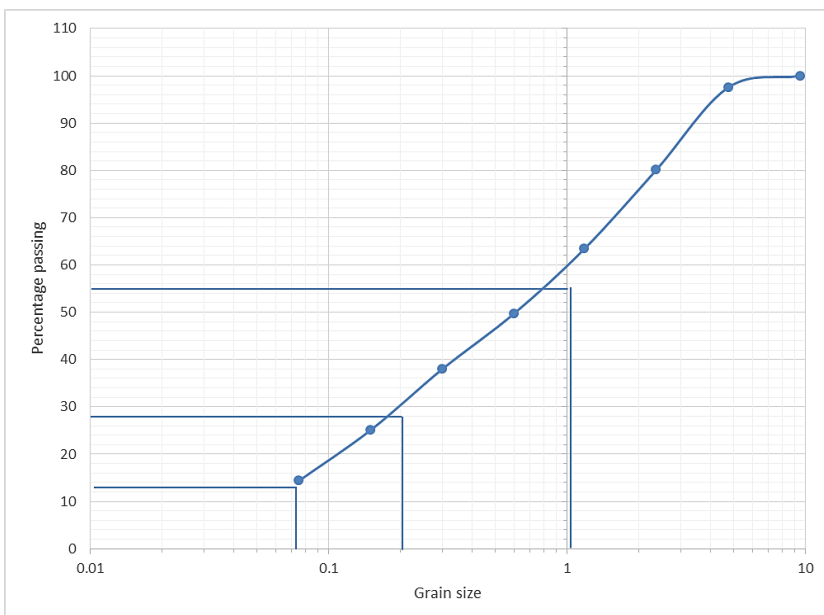
For the graph above,  $D_{10}$ ,  $D_{30}$ , and  $D_{60}$  have all been approximated to have a value of

$D_{10} = 0.08$ ,  $D_{30} = 0.16$  and  $D_{60} = 1.2$

$$C_u = \frac{D_{60}}{D_{10}} = \frac{1.2}{0.08} = 15$$

And

$$C_c = \frac{D_{30}^2}{D_{10} * D_{60}} = \frac{0.16^2}{0.08 * 1.2} = 0.3$$



**Fig.5.** Sieve Analysis for Sample 2

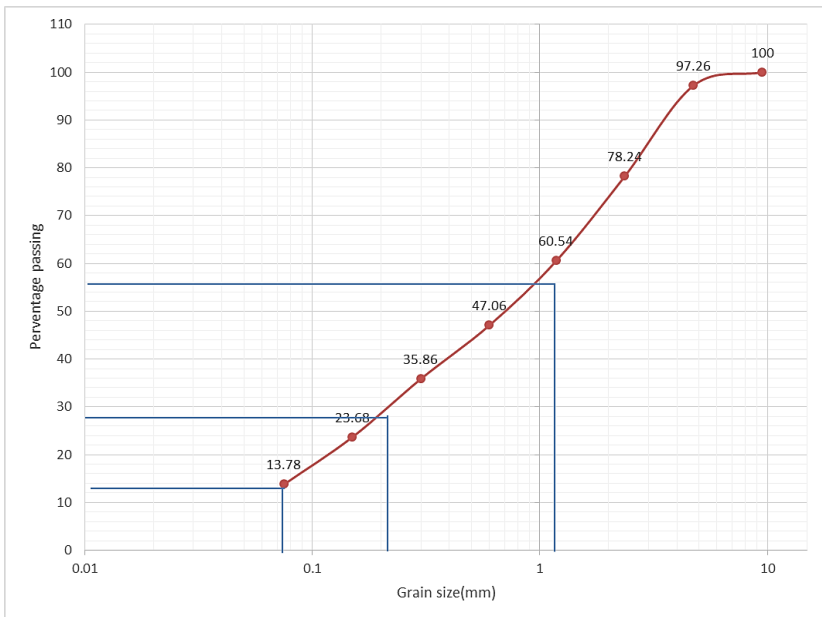
For the graph above,  $D_{10}$ ,  $D_{30}$ , and  $D_{60}$  have all been approximated to have a value of

$$D_{10} = 0.07, D_{30} = 0.12 \text{ and } D_{60} = 1.1$$

$$C_u = \frac{D_{60}}{D_{10}} = \frac{1.0}{0.072} = 14$$

And

$$C_c = \frac{D_{30}^2}{D_{10} * D_{60}} = \frac{0.2^2}{0.072 * 1.0} = 0.6$$



**Fig.6.** Sieve Analysis for Sample 3

For the graph above,  $D_{10}$ ,  $D_{30}$ , and  $D_{60}$  have all been approximated to have a value of

$$D_{10} = 0.07, D_{30} = 0.22 \text{ and } D_{60} = 1.05$$

$$C_u = \frac{D_{60}}{D_{10}} = \frac{1.05}{0.07} = 15$$

And

$$C_c = \frac{D_{30}^2}{D_{10} * D_{60}} = \frac{0.22^2}{0.07 * 1.05} = 0.7$$

The coefficient of uniformity as calculated from the graph above  $C_u = D_{60}/D_{10} = 12$ , the coefficient of uniformity is  $>>4$ , hence, the soil is well graded. Since the soil is well graded, there is no need for any correction in the field.

$$\text{Coefficient of curvature: } C_c = \frac{D_{30}^2}{D_{60} * D_{10}} = \frac{(0.16)^2}{0.10 * 1.20} = 0.21$$

Hence, this further shows that the soil is well graded.

#### 4.0. Conclusion

In the Atterberg limit test, we can conclude that the soil is classified as low plasticity organic clay and low plasticity silt which makes the soil suitable to be used as the base material because the soil would not have the problem of swelling during the rainy season. The higher the plasticity, the higher the swelling tendency when the soil is wet.

According to the federal ministry of works and housing recommendation for particle size analysis, the material to be used as a subgrade for filling or as base material must be less than 35% passing for the 475 $\mu$ m sieve, and if it is more than 35%, the

material is rejected. For this work, the % passing at different sections, and chain ages were 13.2%, 14.4%, and 13.9%, hence, the soil materials at the site are suitable to be used as subgrade for filling or as base materials.

### 5.0. Recommendation

From the result gotten from the work carried out in this study, the following recommendations have been made

- [1] The geotechnical characteristics at different points produce different results and as such, the zones with high clay content should be treated with the utmost care, consideration, and caution during construction.
- [2] Subsequent refill materials should be properly treated before being used to avoid problems after construction.
- [3] The knowledge of soil geotechnical properties and geology of the construction area must be properly understood before any structural work is done as this will go a long way to affect the stability of any work being done.

### Declarations

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#### Consent for publication

*Authors declare that they consented for the publication of this research work.*

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